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AN OPTICAL MAGNIFIER SUITABLE FOR USE WITH A MICRODISPLAY DEVICE

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AN OPTICAL MAGNIFIER SUITABLE FOR USE WITH A MICRO-DISPLAY DEVICE

This application is a divisional of U.S. Patent application Serial No. 10/373,472 filed February 24, 2003, in the name of Cahall, and assigned to the Eastman Kodak Company.

FIELD OF THE INVENTION

This invention relates generally to optical systems and in particular to optical magnifiers incorporated into and/or used in conjunction with other optical components.

BACKGROUND OF THE INVENTION

Optical Magnifiers (also referred to as "eyepieces" or "loupes") are known. Typically, these optical devices are used to allow direct viewing of slides or other small objects or are used as part of other optical systems such as, for example, telescopes and viewfinders.

Conventional optical magnifiers utilize magnifier lenses that provide an enlarged virtual image of a real object in front of a viewer's eye. It is generally preferable that such lenses, in combination with the object being viewed, provide an apparent field of view to the user in excess of +/-10 degrees, in order to avoid the sensation of "tunnel vision". Additionally, these magnifier lenses preferably provide a relatively long eye relief (that is, the distance at which the lens can be held from the eye) in order to allow an object to be comfortably viewed.

Optical magnifiers have also been suggested for viewing electronic displays incorporated, for example, in portable electronic devices. When used to view electronic displays, the same criteria, described above, applies, even though newer high quality micro-displays are now being manufactured with full diagonals of 6 mm or less. In order to obtain a +/-10 degree apparent field of view, such small micro-displays require a high magnification lens (on the order of 15x or greater), which translates to an effective focal length of approximately 17 mm or less. As is known, magnification for this type of optical system is calculated using

the standard formula: M=254 mm/EFL, where EFL is the effective focal length of the lens, measured in mm.

For comfortable viewing by users, including those wearing eyeglasses, it is generally accepted that a reasonable eye relief is approximately 17 mm or greater. As such, in the relative sense, the eye relief should preferably be at least as great as the EFL of the lens (for example, 17 mm in the 15x example described above) for micro-displays of this size. This relationship between eye relief and EFL becomes even more of a concern when shorter focal length (higher magnification) systems are contemplated. This is a new and challenging goal that did not previously exist for larger electronic displays used with correspondingly lower magnification lenses.

In U. S. Pat. No. 4,094,585, E. I. Betensky discloses a three-element all-plastic optical magnifier comprising from the viewing end, a first positive lens group comprising a single element, and a second lens group comprising a bi-convex element and a bi-concave element forming a doublet having the overall shape of a meniscus. This magnifier has a magnification in the range of 13x to 14x. For micro-displays with full diagonals of less than 6 mm, this magnifier does not provide the desired +/-10 degree field of view. Additionally, this magnifier has the added labor expense of cementing two elements to form a doublet, which may be unacceptable for cost-sensitive applications.

In U. S. Pat. No. 5,835,279, I. Marshall and R. Holmes disclose a three-element all-plastic magnifier lens for viewing an LCD in the binocular vision system of a head-mounted display unit. This design has a large (+/-35.8 degree) apparent field of view and a long (17 mm) eye relief. However, the LCD is quite large (33.65 mm full diagonal) and the resulting magnification is only about 11x, making it unsuitable for use with micro-displays of the scale contemplated here. Additionally, when this system is scaled to a magnification of 15x, the eye relief drops to about 12.4 mm, quite short for users wearing eyeglasses.

In U. S. Pat. Nos. 5,909,322 and 5,886,825, J. R. Bietry discloses
two- and three-element plastic designs for magnifier lenses suitable for use in
liquid crystal (LCD) or light emitting diode (LED) micro-display systems.
Although these lenses have a magnification of 16x, high image quality, and long
5   eye relief, these designs contain at least one diffractive surface, for both the two
element and three element forms and/or include a rear meniscus lens which is
concave toward the object and positionable within 5 mm of the object surface. As
a number of newer "micro-display" devices, for example, LCD devices, depend on
light being delivered from the front of the display via a polarizing beam splitting
10 device, a back focal length (BFL) of the lens in excess of 5 mm is often essential
for the placement of the optical magnifier. For micro-displays which require a
BFL in excess than 5 mm, these designs will simply not function.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, a magnifier lens
15 comprises in order from an eye side a first positive power meniscus lens element
having an eye side surface and an object side surface with at least one of the eye
side surface and the object side surface is aspheric; and a second positive power
lens element having an aspheric object side surface convex toward the object side
and an eye side surface, wherein at least one of the object side surface of the first
20 positive power meniscus element and the eye side surface of the second positive
power element is diffractive.

According to another aspect of the invention, an optical system
comprises in order from an eye side a first positive power meniscus lens element
having an eye side surface and an object side surface with at least one of the eye
25 side surface and the object side surface being aspheric; a second positive power
lens element having an aspheric object side surface convex toward the object side
and an eye side surface, wherein at least one of the object side surface of the first
positive power meniscus element and the eye side surface of the second positive
power element is diffractive; and an object to be viewed.

30 According to another aspect of the invention, a magnifier lens
comprises in order from an eye side a first positive power lens element having an

aspheric eye side surface; a second negative power meniscus lens element having an aspheric object side surface; and a third positive power bi-convex lens element having at least one aspheric surface.

5   According to another aspect of the invention, an optical system comprises in order from an eye side a first positive power lens element having an aspheric eye side surface; a second negative power meniscus lens element having an aspheric object side surface; a third positive power bi-convex lens element having at least one aspheric surface; and an object to be viewed.

    According to another aspect of the invention, a magnifier lens
10   comprises in order from an eye side a first positive power lens element having an aspheric surface; and a second positive power lens element having an aspheric surface, the magnifier lens having a back focal length in air, wherein the back focal length of the magnifier lens in air is greater than 5 mm.

BRIEF DESCRIPTION OF THE DRAWINGS

15   In the detailed description of the preferred embodiments of the invention presented below, reference is made to the accompanying drawings, in which:

    FIG.1 shows a sectional view of a first embodiment of the magnifier lens system of the first general form;

20   FIG.2 shows a sectional view of a second embodiment of the magnifier lens system of the first general form;

    FIG.3 shows a sectional view of a third embodiment of the magnifier lens system of the first general form;

    FIG.4 shows a sectional view of a fourth embodiment of the
25   magnifier lens system of the first general form;

    FIG.5 shows a sectional view of a first embodiment of the magnifier lens system of the second general form;

    FIG.6 shows a sectional view of a second embodiment of the magnifier lens system of the second general form;

30   FIG.7 shows a sectional view of a third embodiment of the magnifier lens system of the second general form;

FIG.8 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 1, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm;

5 FIG.9 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 2, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm;

FIG.10 shows a plot of the through-focus Modulation Transfer 10 Function (MTF) of the magnifier lens illustrated in FIG. 3, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm;

FIG.11 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 4, the MTF is 15 polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm;

FIG.12 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 5, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial 20 frequency of 21 line pairs/mm;

FIG.13 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 6, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm; and

25 FIG.14 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 7, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm.

DETAILED DESCRIPTION OF THE INVENTION

30 The present description will be directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with

the present invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

In the following descriptions of example embodiments of the invention, the term magnifier lens is used to describe an optical system. However, a person skilled in the art will understand that the magnifier lens(s) described herein can be used as, for example, an eyepiece with other optical components. As such, the term magnifier lens should not be considered limited to any particular application. Note, that since that light can be directed through the magnifier lens in any direction, the eye position can be replaced by a galvanometer or a rotating polygon with some minor distortion adjustments. Thus, a magnifier lens constructed according to the present invention can be used, for example, in scanner applications. The magnifier lens can also be used as part of a viewfinder system in, for example, a digital or hybrid (digital/film) camera to image a scene displayed on an electronic display to a user's eye for preview and/or review.

Referring to FIGS. 1-7, the terms "front" and "rear" refer to the eye side and object side of the magnifier lens, respectively. In the following examples, 10 is the diaphragm of an eye or other instrument, 20 is a polarizing beam splitter (PBS) or other suitable device for dividing light rays, and 30 is a cover plate protecting an object to be viewed (for example, an image display) 40. The PBS 20 is preferably a partially transmissive/partially reflective device used to illuminate the display front-on via a light source located out of the optical path of the magnifier. Typically, in practice, the PBS 20 (or other beam splitting device, or other light dividing device, etc.) is only necessary for objects to be viewed (for example, image displays) 40 that require front-on illumination.

Although the PBS 20 is shown here as perpendicular to the optical axis 60 of the optical system 50, the PBS 20 is typically tilted at some angle or curved along at least one dimension or both. Additionally, the correction of aberrations due to this non-axially symmetric component would require at least one additional non-axially symmetric feature or component. For these reasons, and with simplicity and cost of the optical system 50 in mind, no attempt to

correct aberrations associated with the PBS was made other than inserting the PBS 20 as a thin flat plate oriented perpendicular to the optical axis 60.

The example embodiments of the invention are illustrated in FIGS. 1-7, and Tables 1-7, respectively. In FIGS. 1-7 and Tables 1-7, the surface radii R

5   are numbered beginning at the front side of the magnifier lens 70 ending at the surface of the object to be viewed (for example, an image display surface) 40. In Tables 1-7, the thicknesses of the lens elements and the airspaces between the lens elements are both labeled as "thickness" and are listed on the same line as the surface preceding the thickness. For example, the first thickness in Table 1

10   corresponds to the distance from the eye diaphragm to the first surface of the first element E_1. Similarly, the second thickness in Table 1 corresponds to the thickness of the first element E_1 in the system. All thicknesses provided in Tables 1-7 are in millimeters. All indices and V-numbers (also known as Abbe numbers) are for the helium d line of the spectrum at a wavelength of 587.6 nm.

15   Additionally, the example embodiments are color-corrected for the visible spectrum by modeling the photopic response of the human eye using equal weights of 510, 560, and 610 nm light.

A magnifier lens 70 of a first example embodiment is depicted in FIG. 1. This magnifier lens 70 includes two lens elements E_1 and E_2. The first

20   lens element E_1 is a positive power meniscus element concave toward the rear, object side. The front, eye side surface of element E_1 is aspheric and the rear, object side surface of element E_1 is spherical. The second lens element E_2 is a positive power meniscus lens element as well. The front, eye side surface of element E_2 is a diffractive and the rear, object side surface of element E_2 is

25   aspheric. Elements E_1 and E_2 are made of plastic and can be molded. The total thickness of the magnifier lens 70, including elements E_1 and E_2 and the airspace between them, is about 8.6 mm. The total thickness from the front, eye side surface of E_1 to the surface of the object to be viewed (for example, an image display surface) 40 is about 16.7 mm.

30   A magnifier lens 70 of a second example embodiment is depicted in FIG. 2. This magnifier lens 70 includes two lens elements E_1 and E_2. The first

lens element E_1 is a positive power meniscus element concave toward the rear, object side. The front, eye side surface of element E_1 is spherical and the rear, object side surface of element E_1 is aspheric. The second lens element E_2 is a positive power meniscus lens element as well. The front, eye side surface of element E_2 is a diffractive and the rear, object side surface of element E_2 is aspheric. Elements E_1 and E_2 are made of plastic and can be molded. The total thickness of the magnifier lens 70, including elements E_1 and E_2 and the airspace between them, is about 8.6 mm. The total thickness from the front, eye side surface of E_1 to the surface of the object to be viewed (for example, an image display surface) 40 is about 16.9 mm.

A magnifier lens 70 of a third example embodiment is depicted in FIG. 3. This magnifier lens 70 includes two lens elements E_1 and E_2. The first lens element E_1 is a positive power meniscus element concave toward the rear, object side. The front, eye side surface of element E_1 is aspheric and the rear, object side surface of element E_1 is diffractive. The second lens element E_2 is a positive power meniscus lens element as well. The front, eye side surface of element E_2 is spherical and the rear, object side surface of element E_2 is aspheric. Elements E_1 and E_2 are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these two elements and the airspace between them, is about 8.1 mm. The total thickness from the front, eye side surface of E_1 to the surface of the object to be viewed (for example, an image display surface) 40 is about 16.2 mm.

A magnifier lens 70 of a fourth example embodiment is depicted in FIG. 4. This magnifier lens 70 includes two lens elements E_1 and E_2. The first lens element E_1 is a positive power meniscus element concave toward the rear, object side. The front, eye side surface of element E_1 is aspheric and the rear, object side surface of element E_1 is diffractive. The second lens element E_2 is a positive power bi-convex lens element. The front, eye side surface of element E_2 is spherical and the rear, object side surface of element E_2 is aspheric. Elements E_1 and E_2 are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these two elements and the airspace between them, is

about 8.4 mm. The total thickness from the front, eye side surface of E_1 to the surface of the object to be viewed (for example, an image display surface) 40 is about 16.5 mm.

A magnifier lens 70 of a fifth example embodiment is depicted in
5   FIG. 5. This magnifier lens 70 includes three lens elements E_1, E_2, and E_3. The first lens element E_1 is a positive power bi-convex element. The front, eye side surface of element E_1 is aspheric (simple conic) and the rear, object side surface of element E_1 is spherical. The second lens element E_2 is a negative power meniscus lens element convex toward the eye side. The front, eye side surface of element E_2
10   is spherical and the rear, object side surface of element E_2 is aspheric (simple conic). The third lens element E_3 is a positive power bi-convex element. The front, eye side surface of element E_3 is spherical and the rear, object side surface of element E_3 is aspheric. Elements E_1, E_2, and E_3 are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these three
15   elements and the airspaces between them, is about 9.8 mm. The total thickness from the front, eye side surface of E_1 to the surface of the object to be viewed (for example, an image display surface) 40 is about 17.9 mm.

A magnifier lens 70 of a sixth example embodiment is depicted in FIG. 6. This magnifier lens 70 includes three lens elements E_1, E_2, and E_3. The
20   first lens element E_1 is a positive power meniscus element, convex toward the eye side. The front, eye side surface of element E_1 is aspheric and the rear, object side surface of element E_1 is spherical. The second lens element E_2 is a negative power meniscus lens element convex toward the eye side. The front, eye side surface of element E_2 is spherical and the rear, object side surface of element E_2 is aspheric
25   (simple conic). The third lens element E_3 is a positive power bi-convex element. The front, eye side surface of element E_3 is spherical and its rear, object side surface is aspheric. Elements E_1, E_2, and E_3 are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these three elements and the airspaces between them, is about 9.5 mm. The total thickness
30   from the front, eye side surface of E_1 to the surface of the object to be viewed (for example, an image display surface) 40 is about 17.2 mm.

A magnifier lens 70 of a seventh example embodiment is depicted in FIG. 7. This magnifier lens 70 includes three lens elements E_1, E_2, and E_3. The first lens element E_1 is a positive power bi-convex element. The front, eye side surface of element E_1 is aspheric (simple conic) and the rear, object side surface of

5   element E_1, is spherical. The second lens element E_2 is a negative power meniscus lens element convex toward the eye side. The front, eye side surface of element E_2 is spherical and the rear, object side surface of element E_2 is aspheric (simple conic). The third lens element E_2 is a positive power bi-convex element. The front, eye side surface of element E_3 is aspheric and the rear, object side surface of

10   element E_3 is spherical. Elements E_1, E_2, and E_3 are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these three elements and the airspaces between them, is about 9.3 mm. The total thickness from the front, eye side surface of E_1 to the surface of the object to be viewed (for example, an image display surface) 40 is about 17.6 mm.

15   The seven example embodiments described above are designed for an object semi-diagonal of 2.4 mm. These embodiments have effective focal lengths between 12.87 mm and 13.05 mm and corresponding magnifications between 19.7x and 19.5x, respectively. Embodiments 1-7 have an apparent field of view of +/-10.5 degrees, an eye relief of 17 mm, and assume a pupil diameter of

20   6 mm. The resulting relative aperture of embodiments 1-7 is about f/2.2. The seven example embodiments have a maximum distortion (absolute value) < 1% and a primary lateral chromatic aberration (absolute value)< 3 microns. Additionally, any one or all of the individual lens elements described above can be made using glass in conjunction with a grinding and polishing or molding

25   manufacturing process.

The embodiments described above are suitable for use with LCD-type micro-displays. This is made possible by designing the magnifier lenses 70 to be approximately telecentric on the display side (i.e., chief rays nearly parallel to the optical axis of the system, which is itself parallel to the display surface

30   normal). It is known that doing so reduces perceived brightness falloff toward the corners of the display (which can be substantial with non-telecentric lenses). In

embodiments 1-7, the maximum chief ray angle (absolute value) on the display side for all of these embodiments is < 3 degrees. Additionally, the embodiments described above are suitable for use with other types of electronic displays and micro-displays, for example, light emitting diode displays such as organic light emitting diode displays, polymeric light emitting diode displays, etc.

Additionally, embodiments 1-7 employ vignetting at the front, eye side surface of the first element E_1. Vignetting stops some aberrated rays near the edge of the pupil from reaching off-axis points in the image plane. This increases off-axis image quality at the expense of reduced illumination in the corners of the image relative to that at the center of the image (i.e., relative illumination). Vignetting in the corner of the image is between 25% and 35% for the embodiments described above. This is well within the (generally accepted) 30-40% vignetting that the human eye can tolerate before it becomes noticeable.

It is well known by those skilled in the art of magnifier design that the human eye can accommodate some degree of field curvature by effectively refocusing (the eye) for different parts of the field. The eye can also tolerate some (typically, lesser) degree of astigmatism. Traditionally, when the tangential and sagittal field curves all lie within 1 diopter of the central focus, the image is reasonably well defined over the field. Also, in the absence of astigmatism, a young observer can focus on the field edge and accommodate about 3 diopters for the center. In embodiments 1-7, the image is permitted to curve somewhat, thereby facilitating the reduction of astigmatism in the magnifier lenses 70. The result is essentially just some degree of field curvature (from the lenses) and the astigmatism associated with the PBS 20. For the embodiments described above, the curvature of the field corresponds to an accommodation of < 0.6 diopters between the center and the edge of the field.

The through-focus MTF plots shown in FIGS. 8-14 are polychromatic (equal weights of 510 nm, 560 nm, and 610 nm light) for the embodiments depicted in FIGS. 1-7, and Tables 1-7, respectively. The MTF plots are shown for 21 line pairs/mm, half the nyquist frequency for a display with

0.012 mm square pixels. Each MTF plot assumes a curved image surface with radius as given in the prescriptions of Tables 1-7.

It should be noted that for the embodiments in FIGS. 5-7 and Tables 5-7, respectively, the polychromatic MTF performance is substantially the same for equal weights of 450 nm, 550 nm, and 650 nm. For the embodiments in FIGS. 1-4 and Tables 1-4, respectively, the polychromatic MTF performance drops somewhat for equal weights of 450 nm, 550 nm, and 650 nm, but may be recovered quite well with a quick re-optimization.

TABLE 1

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	10.20*	ASPHERE(1)	3.710	1.492	57.8
2	9.14	16.4892	1.900		
3	8.62	-22.2252(2)	2.972	1.590	30.8
4	7.90	ASPHERE(1)	2.443		
5	6.79	PLANO	0.330	1.550	55.0
6	6.71	PLANO	4.635		
7	4.93	PLANO	0.725	1.570	55.0
8	4.82	-30.5417			

*DO NOT EXCEED   LENS LENGTH   8.582

NOTES:
1) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1	C=	0.1666667	D=	-0.28952730E-03	F=	-0.93959591E-06
	k=	0.0000000	E=	0.90649168E-05	G=	0.35556391E-07
	VERTEX RADIUS (1/C) =	6.0000			H=	-0.57183989E-09

SURF. 4	C=	-0.0897376	D=	0.79693786E-03	F=	0.24127936E-05
	k=	0.0000000	E=	0.16847998E-05	G=	-0.17226572E-06
	VERTEX RADIUS (1/C) =	-11.1436			H=	0.65623726E-08

2) DIFFRACTIVE SURFACE DESCRIBED BY PHASE EQUATION:

$$\Phi(Y) = \frac{2\pi}{\lambda_0} \left(c_1 Y^2 + c_2 Y^4 + c_3 Y^6 + c_4 Y^8 \right)$$

SURF. 3 λ_0 = 560 NM c_1 = -4.12013E-03 c_3 = -3.46267E-06
                                   c_2 = 7.96815E-05 c_4 = 1.07025E-07

TABLE 2

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	10.20*	6.229	3.851	1.492	57.8
2	9.11	ASPHERE(1)	1.807		
3	8.69	-13.0221(2)	2.946	1.590	30.8

4	8.14	ASPHERE(1)	2.594		
5	6.82	PLANO	0.330	1.550	55.0
6	6.74	PLANO	4.635		
7	4.93	PLANO	0.725	1.570	55.0
8	4.82	-30.5417			

*DO NOT EXCEED   LENS LENGTH   8.604

NOTES:
3) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1+\sqrt{1-(k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 2   C=   0.4044146   D= 0.52788255E-03   F= 0.48822016E-06

         k=   0.0000000   E= -0.51777047E-05   G= -0.48083647E-07

         VERTEX RADIUS (1/C) = 24.7271   H= 0.36767183E-09

SURF. 4   C=   -0.1093386   D= 0.64198372E-03   F= 0.35968081E-05

         k=   0.0000000   E= -0.11253640E-04   G= -0.21871596E-06

         VERTEX RADIUS (1/C) = -9.1459   H= 0.74093706E-08

4) DIFFRACTIVE SURFACE DESCRIBED BY PHASE EQUATION:

$$\Phi(Y) = \frac{2\pi}{\lambda_0}\left(C_1 Y^2 + C_2 Y^4 + C_3 Y^6 + C_4 Y^8\right)$$

SURF. 3 λ_0 = 560 NM C_1 = -4.06429E-03 C_3 = -3.73155E-06

                                  C_2 = 7.15512E-05 C_4 = 1.62241E-07

TABLE 3

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	10.20*	ASPHERE(1)	4.091	1.492	57.8
2	8.95	19.2401(2)	1.264		
3	8.57	-39.0234	2.750	1.590	30.8
4	7.56	ASPHERE(1)	2.441		
5	6.63	PLANO	0.330	1.550	55.0
6	6.56	PLANO	4.635		
7	4.92	PLANO	0.725	1.570	55.0
8	4.83	-30.5417			

*DO NOT EXCEED   LENS LENGTH   8.105

NOTES:
5) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1+\sqrt{1-(k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1   C=   0.1646063   D= -0.20370475E-03   F= -0.70916812E-06

         k=   0.0000000   E= 0.86070374E-05   G= 0.24289232E-07

         VERTEX RADIUS (1/C) = 6.0751   H= -0.31512663E-09

SURF. 4   C=   -0.0603912   D= 0.95297402E-03   F= 0.62224391E-05

         k=   0.0000000   E= -0.15864043E-04   G= -0.47132486E-06

         VERTEX RADIUS (1/C) = -16.5587   H= 0.17717982E-07

6) DIFFRACTIVE SURFACE DESCRIBED BY PHASE EQUATION:

$$\Phi(Y) = \frac{2\pi}{\lambda_0}\left(C_1 Y^2 + C_2 Y^4 + C_3 Y^6 + C_4 Y^8\right)$$

SURF. 2 λ_0 = 560 NM C_1 = -3.32269E-03 C_3 = -1.71275E-06
                                        C_2 = 4.52118E-05 C_4 = 5.78513E-08

TABLE 4

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	10.20*	ASPHERE(1)	4.294	1.492	57.8
2	8.55	8.1991(2)	1.349		
3	8.38	21.6332	2.750	1.590	30.8
4	7.62	ASPHERE(1)	2.441		
5	6.67	PLANO	0.330	1.550	55.0
6	6.59	PLANO	4.635		
7	4.93	PLANO	0.725	1.570	55.0
8	4.81	-30.5417			

*DO NOT EXCEED   LENS LENGTH   8.393

NOTES:
7) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1+\sqrt{1-(k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1   C=   0.1682086   D= -0.36386441E-03   F= -0.13188881E-05
          k=   0.0000000   E= 0.12936727E-04   G= 0.50574451E-07
          VERTEX RADIUS (1/C) =   5.945   H= -0.93964616E-09

SURF. 4   C=   -0.0426814   D= 0.71989155E-03   F= 0.27592984E-05
          k=   0.0000000   E= -0.41520397E-05   G= -0.20084234E-06
          VERTEX RADIUS (1/C) = -23.4294   H= 0.85266176E-08

8) DIFFRACTIVE SURFACE DESCRIBED BY PHASE EQUATION:

$$\Phi(Y) = \frac{2\pi}{\lambda_0}\left(C_1Y^2 + C_2Y^4 + C_3Y^6 + C_4Y^8\right)$$

SURF. 2 λ_0 = 560 NM C_1 = -3.74332E-03 C_3 = 4.01070E-06
                                        C_2 = -5.34761E-05 C_4 = -4.14056E-08

TABLE 5

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	9.10*	ASPHERE(1)	3.380	1.492	57.8
2	8.73	-104.3823	0.181		
3	8.52	32.1466	1.449	1.583	30.1
4	7.57	ASPHERE(1)	1.053		
5	7.99	6.9618	3.698	1.492	57.8
6	7.85	ASPHERE(1)	2.444		
7	6.73	PLANO	0.330	1.550	55.0
8	6.66	PLANO	4.635		
9	4.95	PLANO	0.725	1.570	55.0
10	4.82	-28.7621			

*DO NOT EXCEED   LENS LENGTH   9.761

NOTES:
1) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1+\sqrt{1-(k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

```
SURF. 1    C=      0.1582487   D= 0.0000000E+00   F= 0.0000000E+00
           k=     -1.2126760   E= 0.0000000E+00   G= 0.0000000E+00
           VERTEX RADIUS (1/C) =   6.3194         H= 0.0000000E+00

SURF. 4    C=      0.2284044   D= 0.0000000E+00   F= 0.0000000E+00
           k=     -0.7743398   E= 0.0000000E+00   G= 0.0000000E+00
           VERTEX RADIUS (1/C) =   4.3782         H= 0.0000000E+00

SURF. 6    C=     -0.0868644   D= 0.4399801E-03   F= -0.3529413E-06
           k=      0.0000000   E= 0.4799854E-05   G= 0.8495183E-08
           VERTEX RADIUS (1/C) = -11.5122         H= 0.0000000E+00
```

TABLE 6

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	9.10*	ASPHERE(1)	3.188	1.492	57.8
2	8.69	95.4845	0.335		
3	8.50	26.9536	1.280	1.583	30.1
4	7.66	ASPHERE(1)	0.744		
5	7.82	7.1693	3.314	1.492	57.8
6	7.61	ASPHERE(1)	2.657		
7	6.56	PLANO	0.330	1.550	55.0
8	6.49	PLANO	4.635		
9	4.94	PLANO	0.725	1.570	55.0
10	4.82	-28.9000			

*DO NOT EXCEED   LENS LENGTH   8.861

NOTES:
2) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

```
SURF. 1    C=      0.1627657   D= -0.9597174E-05  F= 0.8515111E-07
           k=     -1.0784800   E= 0.6443622E-07   G= -0.8389589E-09
           VERTEX RADIUS (1/C) =   6.1438         H= 0.0000000E+00

SURF. 4    C=      0.2147075   D= 0.0000000E+00   F= 0.0000000E+00
           k=     -0.9062283   E= 0.0000000E+00   G= 0.0000000E+00
           VERTEX RADIUS (1/C) =   4.6575         H= 0.0000000E+00

SURF. 6    C=     -0.0832591   D= 0.6436675E-03   F= -0.3216570E-06
           k=      0.0000000   E= 0.7271238E-05   G= 0.2184924E-07
           VERTEX RADIUS (1/C) = -12.0107         H= 0.0000000E+00
```

TABLE 7

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	9.10*	ASPHERE(1)	3.339	1.492	57.8
2	8.74	-224.8469	0.210		
3	8.54	26.8436	1.423	1.583	30.1
4	7.61	ASPHERE(1)	0.939		
5	7.85	ASPHERE(1)	3.574	1.492	57.8
6	7.71	-16.4096	2.444		
7	6.64	PLANO	0.330	1.550	55.0
8	6.56	PLANO	4.635		
9	4.91	PLANO	0.725	1.570	55.0
10	4.81	-28.7621			

*DO NOT EXCEED   LENS LENGTH   9.485

NOTES:
3) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2 Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

```
SURF. 1   C=      0.1609088    D=  0.0000000E+00   F=  0.0000000E+00
          k=     -1.3568420    E=  0.0000000E+00   G=  0.0000000E+00
          VERTEX RADIUS (1/C) =    6.2147          H=  0.0000000E+00

SURF. 4   C=      0.2735529    D=  0.0000000E+00   F=  0.0000000E+00
          k=     -1.5674930    E=  0.0000000E+00   G=  0.0000000E+00
          VERTEX RADIUS (1/C) =    3.6556          H=  0.0000000E+00

SURF. 5   C=      0.2075765    D= -0.2473807E-02   F=  0.6771738E-06
          k=      0.0000000    E= -0.1801932E-04   G= -0.1057451E-06
          VERTEX RADIUS (1/C) =    4.8616          H=  0.0000000E+00
```

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the scope of the invention.